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NOTES ON THE GEOLOGICAL SECTION OF MICHIGAN

PART I. THE PRE-ORDOVICIAN

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INTRODUCTION

It is not as easy to summarize the section of Michigan as, for instance, a compact state like Iowa. For one thing the state is so spread out that, turned around by its southeast corner on the map, it would reach beyond New York into the Atlantic Ocean, and turned around by its northwest corner, would extend to Hudson's Bay and into the Dakotas. Again it includes within its borders representatives of probably the oldest land masses, which have been frequently, if not continuously, above sea level ever since they were first elevated. The geological succession may therefore be expected to be interspersed with beds laid down on land and in lakes fresh and salt, and seas like the Caspian and Black, by stream and wind, as well as wave.

Part I includes the pre-Trenton rocks which even the drill has not reached in the Lower Peninsula.

In preparing these notes the state geologist had assistance from Professor Seaman of the College of Mines as to the older rocks to such an extent that it may be best expressed by joint authorship. Indeed what he knows of the Upper Peninsula is so interwoven with what he has learned from and with Professor Seaman that anything he could write would be essentially of that nature.

With regard to the Paleozoic series he has had the advantage of the constant assistance of Mr. W. F. Cooper, and of unpublished reports by A. W. Grabau and N. H. Winchell to examine. Since, however, he differs quite materially from Dr. Grabau, and Dr. Grabau has recently given elsewhere[1] the essential features of his interpretation, no detailed reference to these unpublished reports will

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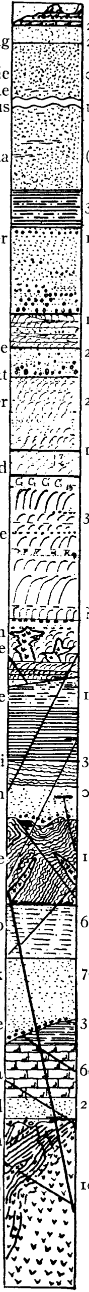
[1] *Bulletin Geological Society of America*, Vol. XVII, p. 567.

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rocks
Ordovician		St. Peter		0 to 75	*Sandstone;* white. waterbearing. in hollows of Calciferous dolomite, but absent often
		Calciferous		255 to 180	Buff and bluish dolomites often sandy, with dolomitic white sandstones.
		Lake Superior Munising		200	*Sandstone;* white or light, waterbearing.
	Neo-Cambrian Saratogan (Potsdam)	Jacobsville		0 to 1500+	*Sandstone:* red and brown and striped with streaks of red clay shale, conglomeritic where it laps upon older formations.
		Redstone		(4000?)	
		Hiatus		not drawn to	scale, the relation of the Freda to the Lake Superior Sandstone being uncertain, probably one formation.
	Upper Keweenawan, perhaps	Freda		(900+)?	*Sandstone:* red, with some felsitic and basic debris, and salt water.
	Mio-Cambrian	Nonesuch		350 to 600	*Shales:* dark, fissile beds, with dark basic fragments, and products of decomposition of lavas copper-bearing.
		Copper Harbor Outer		1000 to 3500	*Conglomerate:* very heavy. red, with large rounded bowlders of all lower formations including jaspilitic iron ores, agate amygdules, gabbro aplites, etc.
Cambrian or Primordial		Lake Shore		1800 to 400	*Traps:* basaltic lavas, and at least one—the "Middle"—conglomerate.
		Great		2200 to 340	*Conglomerate:* very heavy, like the outer conglomerate.
	Keweenawan	Eagle River		2300 to 1417	*Group* of basic lava flows, with *frequent* beds of sediment, Marvine's (c).
	Lower Keweenawan, perhaps eo-Cambrian	Ashbed		1456 to 2400± (50 sediment)	*Group* of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites
		Central Mine		3823 to 25000? (480 sediment)	*Group:* mainly of lavas of the augitic ophite type, with infrequent sediments. At the top is the "Mesnard epidote" and just beneath the heaviest flow, over 1.000 feet thick at times known as the Greenstone. Under this is the Allouez conglomerate. Marvine's No. 15. No. 13 is the Calumet and Hecla conglomerate or lode. The Kearsarge Lode is shortly above 9.
		Bohemian Range		? to 9500+ (500 sediment)	*Group:* mainly of basic lavas but with intrusive and effusive felsites and coarse labradorite porphyrites; also intrusive diabase dikes and gabbro and gabbro aplites.
	Animikean neo-Huronian	Michigamme		1000 to 4000	*Slates:* black and graphitic, and graywacke slates, passing into graywacke arkoses, and quartzites; metamorphosed into staurolite, chiastolite, garnet, and other mica schists and phyllites.
		Bijiki		300 to 800	*Iron formation or schist:* slates with cherty carbonate and soft ore.
		Goodrich		0 to 400+	*Quartzite:* with conglomerate base, and above quartzite or red and green flags, also volcanic material.
	Mio-Huronian	Negaunee		1000±	*Iron formation:* cherty carbonates, altered to jaspilites, etc., with effusives and intrusives altering to hornblende schists and amphibolites.
Huronian		Siamo		600±	*Slates:* graywackes and arkoses and volcanics.
		Ajibik		700±	*Quartzite.*
		Wewe		300±	*Slate:* black largely.
	Eo-Huronian	Kona		600±	*Dolomite:* with siliceous cherty and slaty (schistose) bands.
		Mesnard		250±	*Quartzite:* conglomerate and arkose, becoming a seriate schist or gneiss.
Laurentian		Kewatin (Marinescan) = Laurentian		1000+	Greenstone schists. amphibolites. hornblende schists. sericite schists or crushed felsites, rarely ellipsoidal greenstones and slates and jaspilites, very largely cut by granites, the Laurentian, and numerous other classes of injections.

be necessary. It need not be said that there are many things and many divisions in the geological column upon which further light could be thrown, and it is hoped that before long the Paleozoic geology of the Upper Peninsula may receive more careful attention. But it is the state geologist's feeling that it is well to be sure one is right before going ahead in any change of names, since any such change renders reports less readable even to the geologist, much more so to the teacher, engineer, and others who make casual use of them. This is much more the case when a number of new names are brought in at once. In regard to the scientific questions involved, see the article, "The Geologic Day," *Journal of Geology*, 1906, p. 425.

One general remark should be made. The point of view of the state geologist is largely that of a student of well records and of the drillings returned from them, in which the fossils play next to no part. Not only is the point of view of Dr. Grabau that of a paleontologist, but this must also be remembered, that the study of the paleontologist on outcrops is, in a broad and general way, the study of formations nearer their margins and more likely to be of some other type than simply marine, and if marine deposits, more likely to be deposits of the littoral, and of extreme transgression.

In studying and comparing well records it is a notable fact that certain parts of the geological column seem to be persistent and easily correlated from well to well. Others vary markedly, even in extremely short distances. These are the points where the unconformities come in.

The columnar section is divided into two parts, on different scales, since the thicknesses of the pre-Ordovician units are much greater than those of the later ones. The thicknesses in the column are those derived from wells where the formation is as flat as possible and as far removed from its source. An attempt has been made to draw the column to scale, giving each formation something like its minimum thickness when not obviously cut off by erosion, unconformity, or overlap. The numbers placed along the side, however, show also the customary range up to the greatest thickness of which we can be reasonably sure. Still greater thicknesses may and often have been estimated, but in our judgment may not have had due allowance made for faulting, initial dip, or crushing.

The Laurentian-Keewatin.—These terms we take to have the same stratigraphic meaning, since the relations are of intrusive contact—the former being applied where the areas are largely feldspathic or granitic and light colored, the other when they are mainly of basic rocks, or klastic in a good many cases, of the nature of volcanic tuff (the "Greenstone schist" or "Mareniscan"). In Michigan at least there is comparatively little if any of the commoner types of sediment and limestones, either in their altered or unaltered condition. Many of the schists which are fine grained and slaty enough to pass for altered sediments prove really to be altered felsites, or volcanic ash, or something of that kind. There is, however, a little iron-ore-bearing jaspilitic chert and rarely genuine black slates. Early conditions of erosion before there was any land vegetation would have led to the formation of arkoses and tuffs, and there may have been less ocean of a very different chemical character, accounting for the scarcity of ordinary types of sediment. Generally speaking these rocks are more or less saturated with granitic matter, either in fine-grained aplitic or coarse-grained pegmatitic veins, but the whole rock may be a gneissoid granite. These gneissoid granite bosses generally occupy anticlinal areas, and are the typical Laurentian. Around Marquette there seems to be a compound synclinal with argillites in the upper part and some ill-defined iron-bearing beds which may correspond to the Vermilion Range below, and a great deal of "Greenstone schists." These latter consist of hornblende and chlorite schist and amphibolites, including rarely "ellipsoidal greenstones," and sericite schists altered from felsites throughout, but especially in the lower parts next to the granitic anticlinal bosses. The total thickness one can estimate not less than 1,000 or more than 5,000 feet.

By Bigsby, Maclure, etc., this formation was grouped as gneiss or granite with the hornblende slate under the term primitive; by Houghton and his assistants as syenite, granite, gneiss under the term primary; by Logan as Laurentian; by Foster and Whitney as granite rocks of the Azoic period; by A. Winchell as granitic rock of the Plutonic group; by Credner as the Lower Laurentian of the Eozoic; by Brooks and Pumpelly and many others following them as Laurentian; by Rominger as Huronian; by Van Hise and the

U. S. Geological Survey as Archean (the basement and fundamental complex); by Wadsworth as the Cascade formation. Yet a glance at the various geological maps of Lake Superior shows that, however different the connotation, or meaning, and the theories of the various writers as to relationships, the areas and rocks *denoted* were mainly the same.

Of other terms the "Mona" series is referred to by Foster and Whitney (p. 35), in the European sense, similar, but probably not identical, with the sense of the term used in the *Marquette Monograph.* That and "Kitchi" are intended to be synonymous terms, but include some areas of extra highly metamorphosed Huronian.

The term Mareniscan (*Van Hise Monograph,* 19, p. 473), appears to be a later synonym of Keewatin and it was decided by the joint committee to prefer the latter, but should further discoveries make a local Michigan term needful, may be used, as Wadsworth's term Cascade is later and included, we believe, disparate things. The "Palmer gneiss" appears to be a sheared facies of some of the Huronian members up to the Siamo slate. It is only fair, however, to be ready in regard to so difficult a group as the earliest rocks, to accept a term even though there be some slight inconsistency or error made by the author, provided only that they are not so great as to destroy its usefulness by making uncertain its general application.

Huronian.—The name under which the pre-Cambrian rocks have been assembled in this state has varied. Among the earliest writers who derived their information from direct observation was Credner, then Professor Pumpelly's assistant, who published a paper in Volume II of this survey, and whose thesis for the doctorate was on *Die Gliederung der eozoischen (vorsilurischen) Formations-Gruppe Nord-Amerikas*[1], which is, as far as I know, the first original work published after that of Foster and Whitney. Douglass Houghton's "metamorphic" rocks were in the Huronian. Foster and Whitney, in spite of themselves, divided the formations to be considered, classing them all as Azoic, into granitic rocks (chap. iii); iron ores and associated rocks (chap. iv). Credner calls them all Eozoic, and divides them into Huronian and Laurentian, and the same divisions are used by Brooks and Pumpelly. As between the terms Azoic and

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[1] Published at Halle, 1869.

Eozoic, Proterozoic, Archeozoic, and Archean, we are not prepared to give a final decision, but find the usage of Chamberlin and Salisbury convenient. The terms Laurentian and Huronian have been used pretty continuously in the Lake Superior region, and always with almost the same practical application, so far as this state is concerned. We think, therefore, that we should in them follow Credner and Logan. It is at present agreed to divide the Huronian into three series. A question may arise whether the lowest of these series, which is considerably older than the other two, more eroded, and quite different in distribution, may not be the Grenville or Upper Laurentian. There is, however, no local ambiguity involved, as it has always been mapped with the Huronian in this state.

Eo-Huronian.—We use this term in preference to Lower Huronian, as that was applied to the eo-Huronian and mio-Huronian until the threefold division of the "Marquette" series was recognized. The *Marquette Monograph* calls it Lower Marquette. We had always called it Mesnard (formation or series).[1] The U. S. and state survey now restrict this name to the basal member.

a) Mesnard quartzite. Well exposed on Mt. Mesnard just south of Marquette, finely ripple marked, with about 250 feet of slaty flags toward the base, which is a conglomeritic and arkose quartzite.

There are also brecciation beds, slate, quartzite, and cherty quartzite toward the Kona dolomite above.

It is at times much metamorphosed and sheared and may be confounded with underlying beds, and is at times cut by granites, but by no means as commonly as the Keewatin. We think, too, the granites cutting the Huronian have a different character, being much more inclined to a coarse porphyritic facies.

b) Kona dolomite. This is a very well marked horizon around Goose Lake, but is represented, we believe, on all the ranges and in the original Huronian, being the Randville dolomite of the Menominee Crystal Falls region, and the Bad River formation of the Gogebic Range.[2] But extensive erosion took place before the deposition of the mio-Huronian, generally removing the slates above it and often cutting deep into the dolomite........................600 ft.

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[1] *1892 Report*, p. 65.

[2] Rominger's "Marble" Series, Vol. IV, p. 56.

c) Wewe slates. The slates of Goose[1] Lake, rarely left by the erosion, but exposed on Carp River, Sec. 5, T. 47 N., R. 25 W., and on Sec. 12, T. 47 N., R. 26 W., black and gray slates........300 ft.

Mio-Huronian.—This we are inclined to believe is the main iron-bearing formation, not only of the Marquette range, but of the Menominee range as well. During this time began an epoch of basic volcanics at numerous points which continued into the neo-Huronian and expressed itself mainly in intrusives altered to amphibolite ("diorite"), chloritic schist, "paint rock," and uralite diabase in the mio-Huronian, and mainly in effusives and tuffs in the neo-Huronian.

This is Van Hise and Leith's Middle Marquette; compare also Wadsworth's "Republic" and "Negaunee" formations.[2]

a) Ajibik quartzite. Has often been confused with Mesnard quartzite. Grades upward through slaty phases into *b*)......700 ft.

b) Siamo slate. Grits, flags, and graywackes, and graywacke slates, with volcanic tuffs..................................600 ft.

c) Negaunee formation. The main formation of cherty carbonates and siliceous beds with "greenalite" readily altering into jaspilitic iron-bearing formation..........................1,000 ft.

Near igneous contacts it also changes into grünerite, and other amphibole-magnetite schists.

Neo-Huronian (Animikie).—The relations of this series around Port Arthur on the north side of Lake Superior and along the Gogebic range on the south are such, both as to the overlying and underlying rocks, that there can be but little doubt that they are in general coeval, and the graphitic slate horizon of the upper part seems to be widely identified. We have no hesitation in adopting the term Animikie. There may be some question as to whether it belongs in the Huronian at all. We believe Lawson considers the greatest and most profound unconformity[3] to come at the base of this formation, rather than for instance, between the Mesnard and the Keewatin or greenstone schists, and it must not be forgotten that the Minnesota Survey has held it to be Cambrian.[1] Were the Gogebic range alone to be studied we might agree with Lawson, but there the unconformity at the base of the Animikie represents the elimination of all of the mio-Huronian and most of the eo-Huronian, thus representing a good part of Huronian time. Without question the Animikie is much less disturbed than the older formations, but we are not prepared to say that any one of the breaks before the Keweenawan is the "essential break."[2]

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[1] *Wewe* is Chippewa for "goose."

[2] Though he was never quite able to agree with what seems to us the proper interpretation of the stratigraphy of the same, so that the order as given on p. 66 differs so much from our views that we could hardly use it without producing confusion. See *1892 Report*, pp. 64, 66, 110, etc.

[3] The Eparchean interval.

The divisions are:

a) Goodrich quartzite. This is represented on the Gogebic range by the Palms formation of red and green quartzose slates. But there, as on the Marquette range, there is a conglomerate base, containing pebbles of jaspilite and dolomite as well as granite. Basic tufaceous material is a sign of local volcanic activity, which continued from mio-Huronian (part of Clarksburg formation, etc.) near foci of which the formation may be very thick. Otherwise..........400 ft.

b) Bijiki formation. This is a cherty, iron-bearing member with graphitic slates, on the Gogebic range some 800 feet thick, known as the Ironwood formation and the main iron member. It was not considered in the *Marquette Monograph* so persistent as we really believe it is ....300 ft.

c) Michigamme slate. A group of black, graphitic slates and graywackes, quite wide spread—the Tyler slate of the Penokee-Gogebic range, the Lake Hanbury slates of the Menominee Range. Usually not over 1,000–2,000 feet thick. On the Gogebic range apparently.. 4,000 ft.

Keweenawan.—This term used as a technical name for a rock series is nearly synonymous with Nipigon, which has a year or so priority, but was introduced practically simultaneously in two slightly different senses; and the term Keweenawan has been so much more widely used that the joint committee agreed to retain it. Douglass Houghton included the Lower Keweenawan up to the Great Conglomerate under the general head "Trap rocks" and understood that "strictly in their chronological order" they came after the "metamorphic" slates and quartz rock. The Lake Shore traps were thought of as intrusive dikes, so that he could group the Greater and Outer Conglomerate together under the head "conglomerate" and the rest of the Keweenawan as "mixed conglomerate and sand rock." Foster and Whitney followed his divisions in their mapping, including them as the lowest divisions of the Silurian (which, as in the early editions of Dana, was understood to go down to the Azoic and include the Primordial) and as intimately associated with the Lake Superior sandstone, so much so as not to need any separate formation name. It has already been mentioned that the latter has been referred to various ages from Triassic back. Logan called them the "Upper copper-bearing" rocks; Brooks and Pumpelly the Latin equivalent "Cupriferous," and considered the formation conformable to the Huronian, but covered unconformably by the Lake Superior sandstone, and likely to be more allied to the former than the latter. Irving introduced the term Keweenaw(an), and in *Monograph V*, p. 24, recognized an unconformity (disconformity) of the Keweenawan and Huronian, as well as an unconformity above, especially with the Mississippi Valley Cambrian sandstones. Neither of the unconformities do we doubt. But they appear to be with basal Keweenawan beds disturbed by coeval volcanic activity and faulting, and seem to us quite comparable with inter-Keweenawan phenomena, while the Lake Superior sandstone and the Upper Keweenawan appear to us closely associated not merely lithologically but stratigraphically.[1] We prefer, therefore, for the present, to place the Keweenawan in the Cambrian to express that fact. If we could but be sure that there was indeed a universal cycle of sedimentation and rhythm of geological activity, by which, all the world over, crustal rearrangements and volcanic activity took place simultaneously, while at other times atmospheric conditions universally favored the deposit of limestones or black shales, there would then be more of a temptation to compare our column with the type column in Great Britain and see in the Longmyndian red sandstone and volcanics .... the correlates to the Keweenawan.

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[1] But Logan and Hunt in the original introduction of *Huronian—Esquisse Géologique*, p. 28—considered Huronian as Lower Cambrian of Sedgwick. But at that time, as in the earlier editions of Dana, the Potsdam was classed as Silurian.

[2] Leith in *A. I. M. E. Trans.*, 1906, p. 128.

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[1] See *Annual Report*, Board of Geological Survey of Michigan, 1904, p. 143.

Longmyndian flag stones and shales and Rushton schists	……	the correlates to the Animikie black slate and graywackes.
Bradgate, Beacon Hill and Black Brook hornstones of Charnwood Forest	……	the correlates to the Huronian cherts and jaspilites.

The Keweenawan would then indeed be pre-Cambrian. But far-off lithological correlations have too often proven a will-of-the-wisp.

Lower Keweenawan.—The conglomerates which occur at the top of the Lower Keweenawan and below the Lake Shore traps may perhaps belong stratigraphically to the Upper Keweenawan. They contain a wide variety of pebbles and large bowlders, and are in structure at times suggestive of till.

The main part of this formation cannot at its thinnest point be put down as much less than 15,000 feet. Its base in contact with the upper beds of the Animikie formation has recently (H. L. Smyth) been found north of the Gogebic range. Here its thickness appears to be near 42,500 feet, and I do not think it can possibly be reduced by any allowance for repetition by faulting and initial dip to less than 29,000 feet. Some such thickness of rock with the specific gravity of trap over against an equal thickness of granitic rocks would be needed to produce isostatic equilibrium between the bottom of Lake Superior and the Huron Mountains. Of this thickness only a small fraction is sedimentary and that of a type which may be rapidly accumulated, so that the whole series is not necessarily of great duration. The general characteristic of the lavas which made it up is that, while they run from silicious felsites and quartz porphyries to quite basic rocks, there is nothing ultra basic nor ultra alkaline known. Porphyritic crystals are mainly quartz and feldspar. These have normally crystallized earlier in the magma. A marked second generation of augite is almost unknown. When we come to estimate how much of it is sediment, however, we find that continuous diamond-drill sections would indicate for the major part of it less than 7 per cent. (5.65 per cent. in 8,500 feet, 6.65 per cent. in the 6,247 feet at Isle Royale). The greater the thickness probably the less the per centage. Making detailed allowance for the Great and certain other heavy conglomerates at the top, we get 4,250 feet for the sediments alone—conglomerates and sandstones of very rapid deposition for the most part. A detailed section is given in the *Black River Report,* Annual for 1906, p. 400. Fairly persistent (Isle Royale, Black River, Keweenaw, Mamainse) appear to be the following divisions of the Keweenawan from below:

1. *Bohemian range group* (Irving's (1) and (2), Plate XVII) characterized by numerous flows of labradorite porphyrite type and felsites near the top and frequent intrusions, of straight-walled diabase dikes, of felsite, of gabbro and affiliated red rocks, or gabbro aplites. North of Bessemer, the thickness, igneous sills included, is .... 9,500 ft. There may not be 500 feet of sediment.

2. *Central* (*Mine*) *group.*—Including the "Greenstone group," the "Phoenix Mine group," etc., but only a part of Pumpelly's "Portage Lake series," and just about that part included and well exposed in the workings of the Central mine on a cross-fissure, exposing a good section, examined by Pumpelly and Hubbard, and more recently supplemented by diamond-drill cores on the same property (sections 24, 25, 36, T. 58 N., R. 31 W.). This is a new name we would introduce and define as extending from the Bohemia conglomerate, Marvine's conglomerate (3) or (8) to the "St. Mary's epidote," a sediment, volcanic ash, just above the "Greenstone" and Marvine's conglomerate (15). Characterized by very heavy flows of ophite, some of them hundreds of feet thick, so that, for instance, the "Greenstone," the one at the top of the series, extends beneath Lake Superior, from one side to the other; often proportionately coarse grained.

On Black River there are possibly 25,000 feet including flows. At Portage Lake (7,882), say 8,000 feet.

3. "*Ashbed*" *group.*—This group has been named from the Ashbed Mine, or really originally from a lode so called by the miners, worked at that mine, Marvine's (*a*) and (*b*), Irving's (5) and (6). Including conglomerates 16 to 18, characterized by frequent glomerophyric that is relatively feldspathic and fine grained flows.

In the Tamarack shafts .... 2,400 ft.

The amount of well-marked conglomerate is not over 50 feet but the amygdaloids shade into beds of scoria mixed with red mud called "ashbeds."

4. *"Eagle River" group.*—Marvine's (*c*), characterized by waning volcanic activity shown by numerous (10 or more) sandstones and conglomerates, while the interbedded flows are more of the normal type. In the upper 2,300 feet Marvine estimates 860 feet of sediment. On Black River it is given as 1,417 feet; at the Tamarack as 1,700 ft.

5, 6, and 7. *Copper Harbor conglomerates.*—The conglomerates north of the Eagle River Group were grouped together by Douglass Houghton, who considered the Lake Shore Traps as intrusive dikes. When these were understood to be interbedded flows, the conglomerate was divided into the Great and Outer, respectively, below and above the Lake Shore traps. Hubbard's studies around Copper Harbor have shown that there are at least three heavy conglomerates. It is not probable that the lines between the Great Conglomerate, Lake Shore Trap, and Outer Conglomerate can be drawn at all consistently. Together they cover the period of decadent vulcanism, and it is not at all likely that the flows from these last expiring throes filled the whole basin but more likely they occur irregularly in the conglomerate series. It therefore seems fitting to give a local term to the whole assemblage, treating the Lake Shore traps as a lentil or lentils in the same.

5. *"Great" conglomerate.*—Its thickness, not allowing for initial dips, is say 2,200 feet at Eagle River and Calumet, but apparently much less, 340 feet, on Black River. It has a wide variety of pebbles, but mainly of Keweenawan rocks.

6. *Lake Shore Traps.*—These are apparently thickest near Copper Harbor where using Hubbard's figures, they are about 1,800 feet thick. They are near 900 feet thick at Calumet, but at Black River are only about 400 feet thick. There is at least one well-marked conglomerate in the group. Above this group is the line between the Upper and Lower Keweenawan as drawn by Irving, marked by a cessation of volcanic activity. There are also less dips in general, and very soon a greater variety in detritus.

7. *Outer conglomerate.*—With pebbles representing all the Lower Keweenawan types, including intrusives, amygdules and agates, and also the Huronian jaspilites. Only 1,000 feet are given at

Keweenaw Point, but to the Nonesuch shale on Black River it must be much thicker, not allowing for initial dip at least 3,500 feet. Irving estimates 3,000 feet in the Porcupines.

8. *Nonesuch formation* (from the Nonesuch mine).—Dark colored shales and sandstones—owing its dark color to the basic material—a very significant sign of heavy erosion of Keweenawan traps at some distance. This seems to be a very persistent horizon in lithological character, in spite of not being very thick, being 600 feet on the Porcupines, 500 feet on Black River, and 350–400 on the Montreal.

9. "*Freda sandstone.*" "Main body of sandstone" or "western sandstone" of Rominger (*not* Irving). This seems to need a local name and may well take it from the new stamp-mill town on the shore of Lake Superior, not far from Portage Lake Canal, near which exposures occur, and a well showed a thickness of over 970 feet of sandstones and shales. The relation of this to the "Lake Superior sandstone" in general is a mooted question. It was included in it by early writers. It is much like it lithologically and structurally though felsitic and basic débris and streaks of red clay may be rather more common and the water more saline than in the Lake Superior sandstone around Marquette. The one mantles a granitic boss from which the other was separated, as the Nonesuch shale shows, by extensive exposures of Lower Keweenawan.

Wells in unquestioned Lake Superior sandstone at Lake Linden and Grand Marais show that it is 1,500 feet and over thick. The dips are generally less than those of deposition, so that we cannot make much use of them. Irving estimates the thickness at 12,000 feet, but this is, we believe, based solely on the questionable Montreal river section. We do not, however, think, that it will be decreased below 4,000 feet, if we allow 1,500 feet to the Lake Superior sandstone and make 8,000 feet for the whole upper Keweenawan. We repeat that we are not at all sure that there is any other than an arbitrary dividing line between it and the sandstone which we propose to call Jacobsville.

Lake Superior sandstone.—This term was used by Houghton, and has been customary since, the term Sault Ste Marie sandstone being much later and less used. It is often and quite properly called the Potsdam. It is necessary only to refer to the supposed equivalence with the "New red" Triassic sandstones, held by Jackson, Marcou,[1] and for a time Bell. But accepting its approximate equivalence and even continuity with the Potsdam, there still may be a question as to its exact horizon, which can not be exactly the same everywhere, and might be widely different. It is readily divided in outcrop and in wells into a redder and lower portion and a whiter upper portion. The line between the two may mark the epoch of submergence of the iron-bearing rocks, only a few islands of granite and quartzite, remaining exposed to erosion. In view of the uncertainty of the relation of the three parts of the Lake Superior sandstones, as used by Houghton, separate names seem to us likely to be useful, and we propose not only the term Freda sandstone for that west of the Copper Range, but the term Jacobsville (from Jacobsville where the famous quarries of Portage redstone occur) sandstone for that east of the Copper Range, and we suppose this term may apply to all the Lake Superior sandstone skirting the coast at intervals to Grand Island, while the term Munising sandstone is to apply to the upper 250 feet of Lake Superior sandstone which crosses the bluffs back of Munising, dips southerly, and is white or light colored. Houghton considered the upper "gray sandstone" (700 feet ?) to be unconformable on the lower, dipping south to southeast, while the lower dips to the north. The upper part is well ripple-marked, cross-bedded, friable, with *Fucoides* (?) *duplex* and *Lingulepis prima*, and *L. antiqua*. *Dikelocephalus misa* (?), *Dikelocephalus* (Hall, Pl. XXIII, 3*a–e*, 4), and *Lingulepis primiformis* occur at Iron Mountain which Walcott told Lane was of the Ptychaspis zone. At Marquette Murray reports *Pleurotomaria laurentina* (?) and Scolithus and beds similar at Campment d'Ours close under the Trenton. At Limestone Mountain, below the fairly extensive Trenton fauna, are some conglomeritic beds before we come to the main mass of sandstone. Logan (followed by Grabau)[2] mainly on the strength of the (en)Campment d'Ours Island section concludes that the Lake Superior sandstone may "represent the Chazy, Calciferous, and Potsdam." Beside the Campment d'Ours Island section the Neebish well also indicates a great thinning of the section below the Trenton to the pre-Cambrian along St. Mary's river. But the question remains whether it is by a disconformity and erosion of the Calciferous and St. Peter's down to the Lake Superior sandstone, so that at least most of the sandstone below the "Trenton" limestone is Cambrian and represents the Lake Superior sandstone generally, or whether this sandstone represents the St. Peter's sandstone, the "Potsdam" and Calciferous having been overlapped, or the latter by a shoreward change of facies passed into a basal sandstone, which might represent continuous transgression of the ocean. The St. Peter sandstone is well marked at the Wisconsin line, with a good 200 feet of Calciferous (Lower Magnesian dolomite) under it and also, as records just arrived show, at intervals along Green Bay, at least as far as Rapid River. The Calciferous certainly continues as a thick, well-marked formation well beyond Calciferous station and creek, and according to Rominger clear to T. 45 and 46 N., R. 1 W., and Neebish (Anebish) Rapids. Moreover a few scattered wells to rock as at Newberry in the center of the peninsula do not record any St. Peter's. All these facts favor the first interpretation independent of the fact that it seems to fit better with Berkey's interpretation of the St. Peter sandstone, though to be sure it implies a disconformity at Campment d'Ours Island.[1]

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[1] *Bull. Geol. Soc. Trans.*, Vol. XXXII, p. 102.

[2] *B. G. S. A.*, Vol. XVII, pp. 582, 617.

As has been said the total thickness of this sandstone and the extent to which it is equivalent to the Freda and Upper Keweenawan sandstone are conjectural. As it laps upon the areas of older rocks its thickness diminishes to nothing, and there is often a conglomerate at its base. Its composition is largely quartz and feldspar of the acid varieties, sometimes up to 37 per cent. of orthoclase and microcline. The absence from the formation, except immediately at its contact with other formations, of much basic or even a large amount of felsitic débris which is more abundant in the Upper Keweenawan, is one of the reasons why we believe there can be no great discordance or time interval between this and the Upper Keweenawan. It seems to mark the culmination of the same general depression, when only the granite cores were exposed and finally even these were covered. The upper sandstone which Houghton called the "gray sandstone" he estimated at 700 feet thick. Wells indicate only some 250 feet. The change may indicate that the transgression had gone so far as practically to bury any iron-bearing rocks.

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[1] Cf. Rominger, Vol. I, Part 3, pp. 64, 76, 77, 82, and 83.

Calciferous formation.—This formation appears to have been called by Houghton the sandy limerock, and was said to occur at several points on Sailor's Encampment Island (not Campment d'Ours) near West Neebish Rapids. On Foster and Whitney's map of Lake Superior it was called the Calciferous, a name which it has since generally retained (Winchell's map, 1865, Brooks, Pumpelly, and Rominger's map 1873, and the state survey since, *U. S. G. S. Monograph 36*, 1899, etc.), and has indeed become imbedded in the local nomenclature of Calciferous Creek, a branch of the Au Train river, and Calciferous, a station on the Marquette and Southeastern R. R., so that it may be retained even as a geographic name. "Lower magnesian limestone" has from time to time been used as synonymous. The Hermansville limestone of the *Menominee Special Folio and Monograph*, pp. 31, 494 (Bayley, 1900–04) is this formation, or some part of it. It is given as not over, but near to, 100 feet thick, and equivalent to the Chazy and Calciferous of the east on Rominger's authority. The wells along the Green Bay shore, however, show a fairly constant maximum thickness of about 250 feet. Here flowing wells reach the Lake Superior sandstone between 600 and 700 feet. A late record from Marinette shows, however, 75 feet of white sandstone at the top which may be a trough filled by St. Peter sandstone. The interesting record is in brief:

Quaternary sand	69– 69
Galena and Trenton	256–325
Blue and brown limestones and dolomites	
Sand at 260′, red shale at 290′ (St. Peter horizon ?)	
St. Peter (?)	
White sandstone	75–400
Calciferous	
Brown dolomite	60–460
White sandstone	70–530
Dolomite (Hermansville)	50–580
Lake Superior sandstone	
Upper, white sandstone	195–775
Lower, pink, shading into conglomerate of cherty quartzite, base uncertain	95–870
Huronian	
Cherty quartzite ?	108–978

It looks as though thus close to the Archean land mass the formations were much broken by unconformities and sandstones (of course allowance must be made for imperfect records), and perhaps the term Hermansville will be fittingly applied to the lower 50 feet of the Calciferous. We may compare the triple division of the Calciferous, with the Shakopee dolomite, New Richmond sandstone, and Oneota dolomite of Minnesota.

11. *St. Peter sandstone.*—Outcrops of this have never been identified in Michigan. But the Green Bay wells show a constant water-bearing horizon at about the level where it should appear, and occasionally sandstones, or red clays, and residual dolomites. At this formation we break the column. It is the top of that part exclusively known or seen in the Upper Peninsula. It marks a break which Rominger and others considered the important break which should mark the top of the Cambrian.[1]

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[1] See Berkey, *B. G. S. A.*, Vol., XVII, pp. 229–50.